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For: "DAY/NIGHT BACKLIGHT FOR A LIQUID CRYSTAL DISPLAY"

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BACKGROUND OF THE INVENTION

This invention relates to backlit liquid crystal display devices (LCDs) having a first light source for operation during the day, and a second light source for operation during the night.

LCDs are gaining in popularity for use in systems such as television receivers, computer monitors, avionic displays, aerospace displays, and other military-related displays, where the elimination of cathode ray tube technology is desirable for several reasons. In particular, cathode ray tubes are characterized by large depth dimensions, inordinately high weight and extreme fragility. Additionally, cathode ray tubes require a relatively high voltage power supply in order to sufficiently accelerate the electron beam, and thus sustain the displayed image.

The aforementioned shortcomings of cathode ray tubes are overcome by the flat panel liquid crystal display in which a matrix array of liquid crystal picture elements or pixels are arranged in a plurality of rows and columns. Patterns of information are thereby defined by the two-dimensional array of pixels which, because of differences in the orientation of the liquid crystal material within each pixel, are caused to appear either darkened or transparent.

Liquid crystal displays may be either transflective or transmissive. Transflective displays depend upon ambient light conditions in order to be viewed, i.e.

light from the surrounding environment, incident upon the side of the display facing the viewer, is reflected back to the viewer. Transflective liquid crystal displays cannot, therefore, be used in a dark or low light environment, since there is no light available for reflection off the viewing surface of the display.

Conversely, transmissive liquid crystal displays require the use of illuminating means, such as a tubular fluorescent lamp array operatively disposed on the side of the matrix array of pixels opposite the viewer. This illumination means, or backlight, may also include a backreflector adapted to efficiently redirect any stray illumination towards the matrix array of rows and columns of picture elements, thus ensuring that the displayed image is as bright as possible (given the characteristics of the lighting scheme employed).

In the past, a great deal of research in the field of flat panel liquid crystal display devices has been dedicated to the design of backlighting schemes which optimize viewing and structural parameters of those displays. Particularly, uniformity and intensity of light across the illuminated area has been maximized while maintaining low power consumption and a low overall profile, i.e., a thin assembly.

For example, as disclosed in the commonly assigned U.S. Patent No. 5,161,041, the entire disclosure of which is incorporated herein by reference, integral image splitting and collimating means operatively disposed

between the light source and the rows and columns of liquid crystal picture elements was employed. This integral image splitting and collimating means has the advantages of providing a bright, uniform light to the matrix array of pixels, while maintaining a narrow profile and minimizing the power consumption of prior backlit electronic displays. This bright, uniform light achieves a high contrast display in bright ambient light conditions.

The effect of the integral image-splitting and collimating means is to eliminate local bright spots and pale spots in the display, corresponding, respectively, to the legs and the spaces between the legs of a typical fluorescent lamp, by providing two similar images of the light emanating from each lamp leg. By locating the split images contiguous, one to each other, the area of illumination is effectively enlarged, and a bright, uniform light distribution across a low profile LCD is obtained. In addition to image-splitting, the specific integral image-splitting and collimating means employed in the aforementioned patent provided collimated light. Additionally, when a light diffuser is provided between the integral image-splitter/collimator and the matrix array, wide angle viewability is also achieved. The precise diffuser chosen depends on the application of the LCD.

In preferred forms of the invention U.S. Patent 5,161,041, the integral collimating and image-splitting

means included a thin film having light-refracting, faceted prisms formed on one of its faces. An example of such a film is 3M SCOTCH™ Optical Lighting Film. In preferred forms, this thin 3M SCOTCH™ film is used by laminating it to a clear transparent sheet of glass, ceramic or plastic, and thereafter using it as a layer in a low profile LCD stack.

While the above-mentioned U.S. patent improved the profile and optical characteristics of prior art electronic displays, and also improved lighting efficiencies so as to reduce the power consumption of the displays, that application did not deal with the problem associated with the use of such displays at nighttime, when very low light intensities are desirable. In particular, known devices utilize tubular fluorescent lamps to provide the high intensity light required for high contrast color liquid crystal displays used during daylight operation where high ambient light conditions exist, e.g., for avionic applications. However, when dimmed to the low intensity levels required for nighttime use, fluorescent lamps loose stability and uniformity. Loss of stability is used herein to mean that the fluorescent lamps begin to flicker. Loss of uniformity is used herein to mean that light and dark bands appear along the fluorescent lamp.

Other research regarding the use of LCDs has concentrated on their use when the viewer is wearing night vision goggles (NVG). NVGs are designed to detect

infrared light and are used typically in very low levels of light. The major problem associated with the use of NVGs occurs when stray light, and particularly stray infrared light, is reflected into the NVG, saturating it. The stray light often comes from displays and panel equipment and reflections of the light therefrom.

Night vision goggles operate because of their high sensitivity to very low levels of light, mainly in the near infrared (IR) region of the spectrum (i.e. about 630-1100 nm). Efforts to block the IR region of the displays and panel equipment were unsuccessful because color integrity (particularly of the color red) and the ability to view the LCD at reasonably wide angles from normal (e.g. up to about 60°) could not be achieved. The new sharp cutoff IR filter of my commonly-assigned, co-pending U.S. Patent Application No. 925,193, (filed August 6, 1992 and entitled "Night Vision Goggle Compatible Liquid Crystal Display Device", the disclosure of which is incorporated herein by reference) provided a solution to these problems. This new filter is successful because, while it does cut off the IR region of the spectrum, it does not cut off a portion of the visible red light resulting in an unbalanced white color, and a shifting of the red color towards the orange. The resulting display thus can pass the NVIS-B criteria of Military Standard MIL-L-85762A. Additionally, by combining the new sharp cutoff IR filter of U.S. Patent Application No. 925,193 with the integral image-splitting

and collimating means of U.S. Patent No. 5,161,041, reasonably wide viewing angles may also be achieved.

Again, however, the display of the aforesaid co-pending application utilizes a fluorescent lamp to provide suitable daytime operation. While the problem of NVG saturation was solved by that patent application, the problem of instability and non-uniformity, exhibited by dimmed fluorescent lamps, still exists.

As will be discussed more fully below, the instant invention provides solutions to the above-described problems of the prior art, and improves the compatibility of LCDs with NVGs.

SUMMARY OF THE INVENTION

Generally speaking, this invention fulfills the above-described needs in the art by providing in a backlit liquid crystal display comprising a first source of light, a matrix array of rows and columns of liquid crystal picture elements spacedly disposed from one side of the light source wherein each liquid crystal picture element comprises a pair of electrodes having liquid crystal material disposed therebetween, means for refracting light rays emanating from the light source to provide two similar images thereof, thereby enlarging the area effectively illuminated by the light source, whereby a bright, uniform light distribution is provided in a low profile assembly, the refracting means spacedly disposed between the light source and the matrix array, and means for diffusing light emanating from the light source

operatively disposed between the refracting means and the matrix array, the improvement comprising, a second source of light for night mode operation, spacedly disposed on the side of the first source of light opposite the matrix array, and switch means for selecting between day and night mode light sources.

In an embodiment of the present invention, an infrared light absorbing filter is included in the LCD stack. The infrared filter is capable of preventing substantially all infrared light from being emitted from the display while at the same time transmitting substantially all red light therethrough, thereby to maintain the color integrity of the image of the display, and is spacedly disposed between the integral collimating and image-splitting means and the diffuser.

In another embodiment of the present invention the infrared light-absorbing filter is repositioned within the LCD stack between the two light sources. This embodiment has the advantage of preventing substantially all infrared light from being emitted from the display in nighttime operation while transmitting the maximum amount of light during daytime operation.

The terms "substantially all infrared light" and "substantially all red light" are used herein together to mean that the filter employed is one which creates a reasonably sharp cutoff between the near IR and red spectrum. An example of a filter with an unacceptable cutoff is reported in Abileah et al., "A Full Color AMLCD

with NVG Class B Compatibility" IEEE, AES Magazine (March, 1992) pp. 1237 thru 1241, in Figure 2, p. 1238. The result, as shown in Figure 1, curve (2) of that article, is an unbalanced white color and a shift of the red color toward orange. An example of a filter with an acceptable, reasonably sharp cutoff is shown in Figure 3, p. 1239 of that article. Such a filter, which only achieves a truly sharp cutoff for incident light at angles normal to its surface, may be obtained from WAMCO Corp. (California, U.S.A.) as a "Wamco Night Vision Filter", and has the SPECTRAL TABLE given in the aforementioned co-pending U.S. Patent Application No. 925,193.

The term "low profile" is used herein in accordance with its well-known meaning in the art. Generally speaking, this term refers to an LCD which, through its thinness, does not take up inordinate space, often a critical characteristic or requirement to be met in avionics and aerospace vehicles. The term "low profile" may be defined by the term "LCD thickness". "LCD thickness" is herein defined as overall display thickness including the matrix array, optics, backlight, ballast and dimming circuitry (e.g. when the elements of Fig. 1 are assembled together in an outside box, not shown). To be a "low profile" LCD, its LCD thickness should be less than about 2 inches, while the backlight assembly thickness (e.g., elements 2, 3, 4, 5, 7 and IRF of Fig. 1) is preferably about 1.5 inches or less.

Preferred embodiments of this invention exhibit improved red color coordinates as stated above. In practice, the NVG capability (i.e. compatibility) of these preferred LCDs is tested using the criteria of the MIL-L-85762A Standard for color displays with 0.5 fl intensity. This Standard requires that at all points of the display and at the useful viewing angles for that display, an NRb of less than or equal to 2.2E-09 is exhibited. Certain embodiments as contemplated by this invention conform to the requirements of this Standard. For example, in some embodiments, the numbers at the normal angle at the center of the display will meet the Standard (e.g. NRb = about 2.094E-09), while the numbers near the edges of the display (e.g. NRb = about 8.12OE-10) substantially exceed the requirements of the Standard. Exemplary of such numbers are, again, shown in the aforesaid Abileah et al. article, Figures 6A and 5B. MIL-L-85762A is incorporated herein by reference.

This invention will now be described with respect to certain embodiments thereof, as illustrated in the following drawings, wherein:

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is an exploded, perspective view illustrating a typical embodiment of the subject invention such as might be used in military and avionic applications.

Figure 2A is a graph of the lamp light intensity distribution in which the intensity of illumination is

plotted on the ordinate, and the horizontal position across the viewing surface of an electronic display (not incorporating the improved backlighting arrangement of the aforesaid commonly assigned U.S. Patent No. 5,161,041) is plotted on the abscissa.

Figure 2B is a graph of light intensity distribution in which the intensity of illumination is plotted on the ordinate, and the horizontal position across the viewing surface of an electronic display of the type illustrated in Figure 1, including a reflector, is plotted on the abscissa.

Figure 2C is a graph of light intensity distribution in which the intensity of illumination is plotted on the ordinate and the horizontal position across the viewing surface of an electronic display is plotted on the abscissa, and illustrating by the curve I_s, a typical, known backlighting arrangement, and by curve I_s', the improved backlighting arrangement of the aforesaid commonly assigned U.S. Patent No. 5,161,041.

Figure 3 is a stylistic front elevational view of the matrix array of rows and columns of liquid crystal picture elements of the active matrix embodiment of the electronic color display of the instant invention, schematically illustrating the manner in which the threshold switching elements are operatively disposed between the address lines and one of the picture element electrodes.

Figure 4 is an equivalent circuit diagram of the active matrix embodiment of the array of Figure 3, illustrating the relationship between the liquid crystal picture elements and the anode-to-cathode connected diodes, by which individual ones of the picture elements, schematically depicted in Figure 3, are addressed.

Figure 5 is a fragmentary perspective view illustrating the relative disposition of the elements of one embodiment of an LCD stack, according to the instant invention, which employs an axially aligned array of tubular lamps as shown in Figure 1.

Figure 6 is a fragmentary perspective view, illustrating the relative disposition of the elements of another embodiment of an LCD stack of the instant invention, which employs the optional, additional NVG filter and image-splitting/collimating lens.

Figures 7, 8 and 9 are fragmentary cross-sectional views of the embodiment shown in Figure 5, illustrating the manner in which rays of light, emanating from the axially aligned lighting configuration of Figure 5, are split and collimated by the optical media of the image-splitting/collimating lens array and, thereafter, in Figure 9, are transmitted (or absorbed) by the IR filter as employed in the instant invention.

Figure 10 is a cross-sectional view of the embodiment shown in Figure 5, illustrating the manner in which rays of light, emanating from the nighttime light source of Figure 5, are split and collimated by the

optical media of the image-splitting/collimating lens array.

DETAILED DESCRIPTION OF THE INVENTION

It is to be understood that active matrix liquid crystal displays, which operate in full color and in the transmissive mode, represent the primary choice of flat panel technologies for avionic and military applications because of their sunlight readability, high resolution, color and gray scale capability, low power consumption and thin profile. It is to be specifically noted, however, that while an active matrix liquid crystal display will be described in detail hereinafter as a preferred embodiment, the instant invention can be used with equal advantage in any type of backlit electronic display known to those skilled in the art, for both daytime and nighttime use and in which infrared light emissions may be prohibited or may need to be significantly diminished.

Generally speaking, in order for electronic displays to gain increased acceptance in military and avionic applications, the backlighting of flat panel displays, and particularly active matrix liquid crystal displays, must be improved in light efficiency and reliability. In order for a full color liquid crystal display to possess acceptable contrast under high ambient lighting conditions, e.g. daytime, and because the twisted nematic liquid crystal material, polarizers and color filters result in a display panel which transmits only about 4% -

5% of the incident radiation, the backlighting arrangement must be bright. However, for a liquid crystal display to operate acceptably in low ambient lighting conditions, the backlighting assembly must be able to operate over a large range of intensities. Typically, the bright fluorescent lamps employed in LCDs, which provide acceptable daytime operation, must have dimming ratios of approximately 2000:1 to provide acceptable nighttime illumination. However, when fluorescent lamps are dimmed over such a large range, the result is a non-uniform and unstable light. In other words, the fluorescent lamp flickers and develops light and dark bands.

The daytime backlight assembly of the instant invention, like that of the aforesaid commonly assigned U.S. Patent No. 5,161,041 and the co-pending application S.N. 07/925,193, consumes only about 1.2 watts/square inch of power with a depth dimension of only about one inch. This design increases lamp life, a critical parameter in the design and successful marketing of electronic displays, to approximately 8,000 hours or more from the typical values of about 4,000 hours exhibited by known prior art lighting arrangements. However, the backlight assembly of the commonly assigned patent and co-pending patent application still requires a very large dimming range for nighttime operation. Therefore, the present invention adds a second light source for

nighttime operation which does not need to be dimmed over such large ranges.

Almost all backlighting assemblies designed for active and passive matrix liquid crystal display applications have the same basic components. More specifically, each backlighting assembly usually includes a light source, an optional optical system comprising one or more lenses for altering the nature of the light emanating from the light source, a diffusing material to enable visibility from a wide range of viewing angles, a backreflector to redirect light from behind the backlight lamps toward the matrix of liquid crystal elements, and light source control electronics (ballast). An exploded perspective view of a preferred embodiment of a fluorescent lamp-based backlight assembly of the present invention is illustrated in Figure 1. The backlight assembly depicted therein is represented generally by reference numeral 1, and as is typical in the industry, employs tubular fluorescent lamp 2 as the daytime light source. Of course, lamp 2 may be arranged in any one of a plurality of well-known configurations: it may be serpentined as shown in Figure 1, it may be "U-shaped", or it may be straight. Other alternative lamp configurations may comprise two lamps interleaved in a serpentined configuration or in a square helical configuration. With the exception of the square helical design, the legs of the lamp should be positioned to extend horizontally with respect to the viewer in order

to provide the desired optical effect of restricting the light to a vertical cone, as discussed in greater detail below. A critical parameter of lamp 2, regardless of the configuration of the lamp employed, is the spacing between the legs of the lamp. As will be explained in greater detail below, the legs of the lamp must be spaced a distance equivalent to the inner or emitting diameter of the lamp.

With further reference to Figure 1, the backlight system further includes nighttime light source 3, lens 4, diffuser 5, display element 6, infrared filter IRF, and control electronics 7. Also shown in Figure 1 is an optional location for filter IRF which will be discussed in greater detail below. Display element 6 comprises a plurality of rows and columns of liquid crystal picture elements adapted to be illuminated by lamp 2 and nighttime light source 3. Prior to the advent of the instant invention, LCD backlighting systems included a backreflector in the position where nighttime light source 3 has been placed. The purpose of a backreflector is to redirect light which is not initially directed towards the display element, so that the maximum amount of available light is directed towards display element 6. Therefore, a special feature of nighttime light source 3 is the capability to act as a daytime reflector of light.

Generally speaking, the optional optical element, e.g., lens 4, is provided to alter or enhance the quality of the light emanating from the light source. Lens 4 is

an image-splitting means which enhances the quality of the light incident on display element 6. The light from lamp 2 or source 3 is enhanced by the image-splitting means of lens 4, i.e. it is made to appear more uniform across the face of the display, by splitting the image of the light into two images. Without image-splitting means of lens 4, the light from lamp 2 will appear, to the observer of the display, as local bright spots and local pale spots corresponding to the legs and the spaces between the legs of lamp 2. Similarly, the same effect would be observed when source 3 is turned on and lamp 2 is turned off, because lamp 2 blocks portions of source 3. By splitting the image of the light, the pale spots are effectively filled in.

Figure 2A illustrates the distribution of light intensity directly in front of the serpentine arrangement of lamps 2, depicted in Figure 1, as "unenhanced" by an optical system (i.e., without any image-splitting or diffusing elements). As can be easily discerned from Figure 2A, unenhanced light emanating from the light source will inevitably lead to areas of localized high intensity of illumination on the array of liquid crystal pixels. In other words, local bright spots, such as b, and local pale spots, such as p, would be exhibited in the displayed image and, therefore, degrade image quality. In addition, the sharp cutoff of filter IRF would only truly exist at a viewing angle normal to the surface of the display. Furthermore, the loss of color

integrity would increase in this respect, as one went to even modest viewing angles from normal.

Figure 2B depicts the typical distribution of light intensity of the serpentine arrangement of lamp 2 of Figure 1 to which a backreflector is added. As can be seen, while the total light intensity is increased, local areas of bright spots and pale spots still exist. The curve marked as I_s in Figure 2C illustrates an intensity of illumination that can be expected from prior backlighting designs having a backreflector and a diffuser, but without the optics of the aforesaid patent. In the detailed description of the aforesaid patent, a highly efficient optical system, the integral image-splitting/collimating lens, is disclosed that maximizes light output while achieving a high degree of uniformity across the viewing screen. Curve I_s' illustrates the uniform intensity of illumination achieved when the light source is thus enhanced. The image-splitting means of lens 4 redistributes the intensity of radiation from the high intensity areas to the areas of lower intensity, while maintaining the total integrated light output from lamp 2.

Preferred embodiments of the instant invention, like that of the aforesaid U.S. Patent No. 5,161,041, incorporate two optical components, the image-splitting means and an optional collimating means, into a single, integral image-splitting/collimating means. The image-splitting means of that invention, as well as that of the

preferred forms of the instant invention was, and is here, adapted to collimate light passing therethrough due to the presence of multi-faceted prisms formed on the surface thereof. Specifically, engineered facets of close tolerances will not only achieve the desired optical effect of splitting the image, but will also collimate each image. Additionally, by positioning the legs of lamp 2 and the facets of lens 4 both to extend horizontally with respect to the observer, collimation of the light will be primarily in the vertical direction. This restricts the emitted light to a vertical cone thereby reducing canopy glare and NVG saturation, as complained of by pilots. It is to be noted, however, that the present invention is fully operative when lens 4 incorporates image-splitting means only.

As reported in the aforesaid patent, it has been found that a material ideally suited for use as an integral image-splitting/collimating means is 3M SCOTCH™ Optical Lighting Film, which may be subsequently laminated onto a transparent substrate, such as glass, other ceramic, or a synthetic plastic resin, and used in the LCD. The desired image-splitting effect, which is obtained with the 3M SCOTCH™ Optical Lighting Film, creates uniform lighting by effectively filling in the pale spots corresponding to the spaces between the legs of lamp 2. This invention adopts such an embodiment as preferred.

By employing this integrally formed image-splitting/collimating means, it is thus possible to achieve the desired optical effects without an increase in the profile of the display, as compared to other non-integrally formed optical systems. Indeed, since the distance between the two similar images provided by the image-splitting/collimating means 4 is a function of the operative spacing of lens 4 from lamp 2 (i.e. the more distant the lens from the lamp, the farther apart the two images will appear), and since it is desired that the distance between the two images be controlled so that the two images are immediately adjacent (i.e. contiguous) one another, it is possible, indeed desirable, to dispose image-splitting/collimating means 4 in close proximity to lamp 2.

Optimal uniformity of light is attained when lens 4 is positioned a distance from the plane through the average centerline of the legs of lamp 2, equal to the inner or emitting diameter of lamp 2, and when the spacing between the legs of lamp 2 is also equal to the inner or emitting diameter of lamp 2. In addition, it has been found that nighttime light source 3 operates effectively without the need for a separate set of optical components, thereby maintaining the thin profile of the display device. As will be explained, however, a separate set of optical components, including an integral image-splitting/collimating lens and/or an infrared

filter, may be supplied between the two light sources while maintaining the thin profile of the display device.

As stated earlier, nighttime light source 2 of the instant invention utilizes a flat panel which acts as a daytime reflector of light but as a nighttime emitter of light. In the preferred embodiment of the instant invention, this flat panel is a flat electroluminescent (EL) panel having a relatively low intensity, e.g. 25fL, but any other light source having equivalent capabilities may be employed. The EL panel, however, is not as efficient a reflector of light as conventional backreflectors. The efficiency of the EL panel as a reflector may be increased by the addition of a transparent reflective coating. The integral image-splitting/collimating means 4 will split the images of the EL light passing between the grid lines of lamp 2 in exactly the same manner as the light from lamp 2, i.e. the image of the light passing between the legs of fluorescent lamp 2 is split into two similar images. By positioning integral image-splitting/collimating means 4 as stated above, the split images of the light of the EL panel are contiguous one to the other and, in fact, may overlap to some small extent. Therefore, the problem of one light source blocking the light path of the light source underneath is eliminated without increasing the thickness of the LCD.

Illumination of an EL panel is achieved through electrical excitation of a phosphor. Typically, the EL

assembly consists of several layers, including a transparent electrode, the phosphor and top and bottom covers. Phosphors are available to provide a white light, as well as a variety of colored light, including violet, bluegreen, green and yellow. Excitation of the phosphor is through electrical leads provided in the EL assembly. Power requirements are generally specified for 115 VAC 400 Hz operation, but may range above or below that specification, depending upon the application. DC operation is possible, however, a DC to AC converter is required. EL assemblies are available in thicknesses ranging from about .5 mm to 1.5 mm, and thereby contribute to the desired thinness of the display. In the instant invention, the EL panel may be switched on and the fluorescent lamp switched off by the use of a manual switch. A manual or automatic brightness control may also be incorporated in the instant invention. These switches are not shown for convenience.

In the preferred embodiment of the present invention, nighttime light source 3 is a single flat EL panel such as the Perma-Light, white color panel manufactured by Quantex Corporation of Rockville, Maryland. The EL panel supplies a white light with an intensity at the face of display device 1 of approximately 1.0 to 1.5 fL. By using conventional circuitry within the skill of the artisan, this nighttime intensity can be dimmed down to, for example, as low as 0.05 fL or less, if desired. The single EL panel has the

advantage of having a single pair of electrical leads. Alternative configurations of EL panel such as a series of separate thin panels corresponding to the spaces between the legs of lamp 2 or a single panel having several fingers corresponding to the spaces between the legs of lamp 2 could be employed.

While the EL panel provides a low intensity backlight for nighttime operation which is stable and uniform, in contrast to the characteristics exhibited by fluorescent lamps when dimmed down for nighttime operation, two other advantages of this new configuration are realized. First, when NVG compatibility is required, the NVG filter IRF can be placed behind the fluorescent lamp, and thereby filter only the nighttime backlight light source. Second, a second optional integral image-splitting/collimating lens can be placed directly in front of the EL panel with the grooves positioned horizontally with respect to the viewer to provide collimated light to filter IRF in its optional position.

Returning now to Figure 1, diffuser 5 of known and conventional design is provided to scatter collimated light so that it will illuminate liquid crystal display 6 in all directions and provide acceptable off-axis (wide angle) viewing (e.g. 0° - 30° and preferably about 60° or more). However, due to the high degree of uniformity of light provided by the image-splitting/collimating lens of the aforesaid patent, it is not necessary to diffuse the light to the extent necessary in prior art backlight

assemblies, and thus the profile of backlight assembly 1 is further reduced. While conventional diffusers made from, for instance, a roughened polymer sheet, may be employed in the instant invention, holographic diffusers or directional non-holographic diffusers may be employed. The benefit of holographic or directional non-holographic diffusers is to provide some control over the direction of diffusion, thereby preventing loss of light in non-desired angles.

Backlight assembly 1 further includes in conventional fashion (not shown, for convenience) lamp and EL panel control electronics having provisions for lamp starting, ballast 7 and dimming circuitry.

Referring now to Figure 3, there is depicted therein a typical matrix array of rows and columns of discrete liquid crystal display picture elements, said matrix array being generally designated by the reference numeral 10. Each liquid crystal display picture element or pixel 12 includes two spacedly disposed pixel electrode plates with a light-influencing material, such as a liquid crystal composition, operatively captured therebetween. (The electrode plates and the light-influencing material will be discussed in detail with respect to Figure 4). Each of pixels 12 further includes a threshold switching device or a plurality of threshold switching devices for selectively applying an electric field across the liquid crystal composition when the electric field exceeds a predetermined threshold value.

More specifically, matrix array 10, which defines liquid crystal display 6 of the instant invention, includes a first set of X address lines 20, 22 and 24; a second set of Y address lines 26, 28 and 30; and a plurality of liquid crystal picture elements 32, 34, 36, 38, 40, 42, 44, 46, and 48. The display further includes at least one isolation or addressing element 50, 52, 54, 56, 58, 60, 62, 64, and 66, operatively associated with and electrically connected to each respective picture element. As should be readily apparent to the reader from even a cursory review of Figure 3, X address lines 20, 22 and 24 and Y address lines 26, 28 and 30 cross over one another at an angle, so as to define a plurality of spaced crossover points associated with respective liquid crystal picture elements 32-48. Picture elements 32-48 are formed on a transparent substrate, such as glass, and are distributed thereover in spacedly disposed relation, so as to define interstitial spaces therebetween.

As can be ascertained from a perusal of Figures 3 and 4, each of threshold devices 50-66 is shown to be diodes. It is to be recognized, however, that other types of bi-directional switching devices, e.g., field effect transistors (TFT, thin film transistors), may be utilized to equal advantage. While diodes are preferably coupled in non-opposing series relation with a first one of the pixel electrodes, other types of switching elements may employ different electrical

interconnections. The diode type of switching arrangement will now be described in greater detail, with respect to Figure 4.

In Figure 4, matrix array 10' includes a plurality of substantially parallel address line pairs 20, 20', 22, 22', 24, and 24', which are the row select lines, and a plurality of substantially parallel column address lines 26 and 28. Column address lines 26, 28 and 30 cross row select address line pairs at an angle and are spaced from row select address line pairs to form a plurality of crossover points therewith. Preferably, column address lines cross row select line pairs at an angle which is substantially perpendicular thereto.

Since, as mentioned hereinabove, each of the pixels are identical, only pixel 12 will be described in detail in the following paragraphs. Pixel 12, as can be seen from the figures, includes a pair of threshold devices 74 and 76 which are electrically coupled together at common node 78. Threshold devices 74 and 76 are shown as diodes in this embodiment, and are electrically coupled together in non-opposing series relationship between row select address line pair 20 and 20'. Although threshold devices 74 and 76, in accordance with certain embodiments of the invention are diodes, the devices can be of any type which provide a high impedance to current flow when reverse-biased, and a comparatively low impedance to current flow when forward-biased. Therefore, any bi-directional threshold switch or field effect transistor

(e.g. TFT, thin film transistor or MIM, metal-insulator-metal transistor) can be utilized with equal advantage. Of course, more conventional electrical interconnections would be employed with field effect transistors. The switching devices are preferably formed from deposited layers of semiconductor material such as, by way of example and not of limitation, amorphous silicon alloy.

Picture element or pixel 12 further includes a pair of electrode plates 80 and 82 which are spaced apart and facing one another. Operatively disposed in the space between electrode plates 80 and 82 is light-influencing material 84. The term "light-influencing material" is defined, and will be used herein, to include any material which emits light or can be used to selectively vary the intensity, phase or polarization of light either being reflected from or transmitted through the material. In accordance with the preferred embodiment of the invention, light-influencing material 84 is a liquid crystal display material, such as a twisted (TN) nematic liquid crystal material. In any event, electrode plates 80 and 82, with liquid crystal material 84 disposed therebetween, form storage element 86 (or capacitor) in which electric charge can be stored. As illustrated, storage element 86 is coupled between common node 78, formed by electrically connected threshold devices 74 and 76, and column address line 28.

Still referring to Figure 4, matrix array 10' further includes row select driver 90 having outputs R-

1a, R1b, R-2a, R-2b, R-3a, and R-3b electrically coupled to row select line pairs 20, 20', 22, 22', 24 and 24'. Row select driver 90 provides drive signals at the outputs thereof to apply first operating potentials which are substantially equal in magnitude and opposite in polarity between the row select address line pairs to forward bias the threshold devices 74 and 76 to, in turn, facilitate the storage of electric charge in the storage elements coupled thereto. The row select driver also applies second operating potentials which are substantially equal in magnitude and opposite in polarity between the row select address line pairs to reverse bias the threshold devices to facilitate the retention of the electric charge stored in the storage elements coupled thereto.

Lastly, matrix array 10' includes column driver 92. Column driver 92 includes a plurality of outputs C1 and C2 which are coupled to column address lines 26 and 28, respectively. Column driver 92 is adapted to apply a charging potential to selected ones of column address lines for providing electric charge to be stored in selected storage elements during the application of the first operating potentials to the row select address line pairs by row select driver 90.

In the embodiment of the matrix array of rows and columns of picture elements that combine to make up the improved matrix array 10', described above, a "balanced drive" scheme for addressing each discrete one of the

pixels is preferred. In this driving scheme, the operating potentials applied to the row select address line pairs are always substantially equal but opposite in polarity. Assuming that the current-voltage characteristics of each of the diodes are substantially equal, a voltage of substantially zero volts will be maintained at common node 78, at least when the diodes are forward-biased. Thus, the voltage applied on column address line 28 to charge storage element 86 no longer needs to take into account the voltage drop across and/or parasitic charge build-up on one or both of threshold devices 74 and 76. Therefore, each pixel in the matrix array of rows and columns may be charged to a known and repeatable value, regardless of its position in that matrix array. This permits improved gray scale operation resulting in at least 15 levels of gray scale in large area active matrix displays of the twisted nematic liquid crystal type using normal fluorescent back illumination. The pixels can also be charged more rapidly, since the retained charge in the diodes associated with each pixel, when they are reverse-biased, need not be initially dissipated to charge the storage elements. This is because this charge is dissipated when the diodes are first forward-biased. A complete description of this driving scheme can be found in U.S. Patent No. 4,731,610, issued March 15, 1988 to Yair Baron et al. and entitled "Balanced Drive Electronic Matrix System and Method of

Operating the Same", the disclosure of which is incorporated herein by reference.

Turning now to Figure 5, there is depicted in a fragmentary perspective view one embodiment of the instant invention. As can be seen, this embodiment adopts as its basic environment the configuration of Figure 5 in the aforesaid patent. In this embodiment of the invention, integral image splitting/collimating means 102 and infrared filter IRF are operatively disposed so as to provide for low profile electronic display assembly 11. Achieving a low profile or depth dimension of the display is important to the preferred embodiments of this invention. It is dependent on the type of lighting assembly, the material from which the threshold devices are fabricated, the on-board electronics, the multiplexing schemes, and most importantly, the optical arrangement by which light is refracted, diffused and transmitted to the viewing audience. In most instances, as envisioned herein, the depth dimension of "LCD thickness" is maintained below about 2 inches, and preferably at about 1 to 1.5 inches.

There are six (6) basic elements which combine to form electronic display assembly 11 depicted in Figure 5. The uppermost element is the generally rectangularly shaped matrix array 105 upon which the rows and columns of active matrix liquid crystal picture elements, as well as the associated drive circuitry described in the preceding paragraphs, are disposed. The lowermost

element is a thin, generally rectangularly shaped back panel 98 upon the interior surface of which is a thin sheet of electroluminescent (EL) material. An EL material supplying a white light with an intensity of approximately 25 fL is preferred. The EL material operates as a nighttime emitter of light, but as a daytime reflector of light. Disposed immediately above EL panel 98 is an array of light sources 100 (such as a continuous bent fluorescent tube) from which radiation emanates and either passes directly towards the matrix array of picture elements 10 or is reflected off the reflective EL panel and then passes upwardly toward matrix array 10. Next, integral image-splitting/collimating means 102, as described in the aforesaid patent, is operatively located between array of light sources 100 and matrix array of picture elements 105. Thereafter, infrared filter IRF is disposed, followed by diffuser 104. It is the combination of these elements which defines the profile, preferably the low profile, of the electronic display of the instant invention.

More specifically, it is important to note that lighting is one of the critical parameters which is employed in assessing the visual appearance of a liquid crystal display. Not only is it essential that the image of the display appear clear and bright to the viewers thereof, but it is also important that the image be substantially as clear to viewers disposed at an angle

relative to the vertical plane of the viewing screen of the display. The structural and optical relationship existing between the array of light sources and integral image-splitting/collimating means 102 and the location and type of diffuser helps to determine the clarity and viewing angle of the display.

In the embodiment of the invention illustrated in Figure 5, the array of light sources 100 is configured as one elongated, serpentined fluorescent lamp arranged in a specific pattern or lighting configuration, and having each section of lamp disposed in a generally horizontal plane. More specifically, the array, regardless of configuration, will be arranged to uniformly distribute radiation emanating therefrom over the entire surface area of the matrix of rows and columns of picture elements 105. To this end, the light array is shaped in a serpentine pattern which may include a plurality of elongated lamps, such as 100a-100e, each lamp of which has a longitudinal axis parallel to the longitudinal axis of the other major lamp sections. The length of each longitudinal lamp axis may be selected to be generally co-extensive with the length dimension of the matrix array of picture elements. The configuration of lighting array 100 also includes curved end sections, such as 101c-101d. The number of the elongated axial sections of the lamps and the number of the curved end sections of the lamps must be sufficient to bathe the entire width dimension of the matrix array of picture elements 105

with a uniform shower of illumination. EL panel 98 is configured, preferably, to be of the same edge-to-edge dimensions, i.e. co-extensive with, the edges of light source 100. As explained above, light source 100 may be configured in several different ways to equal advantage. Use of a square helical arrangement would, however, require that two image-splitting means arranged with the grooves positioned perpendicularly to each other be employed to provide the desired optical effects explained above.

Image-splitting/collimating means 102 is formed as an integral unit. The integrally formed image-splitting/collimating means is, as discussed hereinabove, preferably fabricated of 3M SCOTCH™ Optical Lighting Film which is subsequently laminated onto a transparent substrate, such as glass, a ceramic or plastic. By employing an integrally formed image-splitting/collimating means, it is thus possible to achieve two desired optical effects, image-splitting and collimation, without an increase in the profile of the display. Indeed, since the distance between the two similar images provided by the image-splitting/collimating lens is controlled by the operative spacing of the lens from the light source (i.e. the more distant lens 102 from the light source, the farther apart said two images appear) and since it is desired that the distance between the two images be controlled so that said two images are immediately adjacent (i.e.

contiguous) one another, it is possible, indeed desirable, to dispose the image-splitting/collimating lens in close proximity to light source 100. Therefore, in the preferred embodiment of the invention, image-splitting/collimating lens 102 is spaced from light source 100 to provide two images immediately adjacent (i.e. contiguous) one another. As is illustrated in Figure 5, the image-splitting/collimating lens is also preferably used in conjunction with diffuser 104 to further enhance the uniformity of the light emanating from light source 100. However, in the instant invention, filter IRF must be between lens 102 and diffuser 104, so that filter IRF receives, to the extent possible, collimated light to achieve the purposes of this invention.

Another embodiment of the present invention is depicted in Figure 6. This embodiment is substantially similar to the embodiment depicted in Figure 5 but includes a second optional image-splitting/collimating means, and the infrared filter is repositioned within the LCD stack. The stack includes, in addition to the matrix array of rows and columns of picture elements 305, diffuser 304, image-splitting/collimating means 302, fluorescent lamp 300 and EL panel 398, IR filter IRF' and image-splitting/collimating means 302'.

Infrared filter IRF' may be positioned in the stack, as depicted in Figure 6, to filter only the nighttime backlight, since the purpose for the infrared filter is

to improve the performance of the display at nighttime when NVG's are used. Use of filter IRF' only, will in fact, increase the daytime intensity of the LCD.

Image-splitting/collimating means 302' may be added to the LCD to provide collimated light to filter IRF'. Lens 302' would also be positioned with the grooves extending horizontally with respect to the viewer to collimate light mostly in the vertical direction. By so restricting the vertical viewing angles, nighttime canopy reflections are reduced or eliminated. The integral image-splitting/collimating means 302 is retained to provide necessary optical characteristics during daytime operation.

Turning now to Figures 7 and 8, there is depicted therein a cross-sectional view provided to demonstrate the manner in which rays of light "r" emanating from lamps 101b and 101c of lighting configuration 100 are collimated to present a sharp image to the viewing audience of the liquid crystal display of the instant invention. More particularly, there is depicted in Figure 7 two lamp segments 101b and 101c, of the embodiment of the light configuration, wherein the longitudinal axes thereof are disposed in substantially parallel alignment. As can be seen from a perusal of Figure 7, rays of light "r", emanating from the two parallel but spacedly disposed lamps, are directed upwardly through the relatively thin image-splitting/collimating lens 102. The upper surface, the

surface opposite light source 100 of image-splitting/collimating lens 102, is engineered so as to comprise a series of aligned 45°, multi-faceted prisms 103. Prisms 103 are aligned such that the longitudinal extents thereof are substantially parallel to the longitudinal extents of substantially parallel lamps 100a and 100b. At both planar air-to-material interface 102Z and faceted material-to-air interface 102I thereof, the rays of light are collimated and transmitted in collimated fashion.

Figure 8 is presented to schematically illustrate how the above-referenced aligned facets of prisms 103 inherently operate to provide the image-splitting effect. This, of course, also illustrates the inherent characteristics of operation of the aforesaid 3M SCOTCH™ Optical Lighting Film when used in this invention. As illustrated with reference to a segmented arc of lamp 100c having mid-point B and extremities A and C (these points being designated for convenience of illustration, it being understood that lamp 100c is a circular tube), certain rays of light are reflected backwardly while others are allowed to exit in collimated fashion from lens 102. To the observer located at "eye", this inherently results in a "split image" 1 and 2, the spacing of which, as aforesaid, is governed by the distance between lamp 100c and lens 102. In this way, uniformity, as well as collimated light, is achieved.

The importance of this is illustrated in Figure 9. As illustrated, by using integral collimating/image-splitting means 102 properly located above lamps 100c and 100d to create contiguous images, substantial uniformity of illumination is achieved. In addition, by sending to filter IRF collimated light uniformly across its surface, not only is virtually all infrared light absorbed (i.e. virtually none transmitted to matrix array 10), but color integrity is maintained, and by use thereafter of diffuser 104, the viewing angle problem inherent to sharp cutoff filter IRF is overcome at all reasonable viewing angles (e.g. 0-30° and preferably 0-60° normal to the surface of panel 10). Figure 9 also illustrates the ability of EL panel 98 to operate as a daytime reflector of light, thereby providing enhanced brightness during daytime operation.

Figure 10 demonstrates the manner in which light emanating from EL panel 398 is split and collimated to present a sharp image to the viewing audience of the LCD of the instant invention. It is apparent from a comparison of Figure 10 with Figures 7, 8 and 9, that light emanating from EL panel 398 is split and collimated in the same way as the light emanating from fluorescent lamp segments 101b and 101c.

Once given the above disclosure, many other features, modifications and improvements will become apparent to the skilled artisan. Such other features, modifications and improvements are therefore considered a

part of this invention, the scope of which is to be determined by the following claims.